Semi-Annual Report
January - June 1994

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## I. Task Objectives

The Moderate Resolution Imaging Spectroradiometer (MODIS) being developed for the Earth Observing System (EOS) is well suited to the global monitoring of atmospheric properties from space. Among the atmospheric properties to be examined using MODIS observations, clouds are especially important, since they are a strong modulator of the shortwave and longwave components of the earth’s radiation budget. A knowledge of cloud properties (such as cloud cover, cloud thermodynamic phase, optical thickness, and effective particle radius) and their variation in space and time, which are our task objectives, is also crucial to studies of global climate change. In addition, with the use of related airborne instrumentation, such as the Cloud Absorption Radiometer (CAR) and MODIS Airborne Simulator (MAS) in intensive field experiments (both national and international campaigns, see below), various types of surface and cloud properties can be derived from the measured bidirectional reflectances. These missions have provided valuable experimental data to determine the capability of narrow bandpass channels in examining the Earth’s atmosphere and to aid in defining algorithms and building an understanding of the ability of MODIS to remotely sense atmospheric conditions for assessing global change. Therefore, the primary task objective is to extend and expand our algorithm for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from MODIS. The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

## II. Work Accomplished

### *a. MODIS-related Algorithm Study*

The revision of the MODIS Algorithm Theoretical Basis Document (ATBD) was completed by Michael King, Si-Chee Tsay and Steven Platnick and delivered to the EOS Project Science Office on time. The title of this ATBD is the “Theoretical Basis of Cloud Retrieval Algorithms for MODIS: Cloud Cover, Thermodynamic Phase, Optical Thickness and Effective Particle Radius.” The initial MODIS β-version software (cloud retrieval algorithms) also has been delivered by Menghua Wang to SDST. This package includes eight lookup tables (4 for the reflection functions, 3 for the flux parameters, and 1 for asymptotic parameters) and one cloud retrieval code.

TABLE 1. Summary of approximate maximum error in retrieving effective radius for MAS near-infrared channels and AVHRR channel 3 (3.7 µm). Calculated for $\mu = 0.95$, $\mu_0$ variable, and $r_e$ from 5-20 µm. See text for details.

| Band | $\langle R^{\lambda} \rangle$ *vs* $R^{\langle \mathrm{Mie} \rangle}$ | $+\lambda_c$ shift (+13% of BW) | $-\lambda_c$ shift (–13% of BW) | $\tau_c$ | Errors due to sensor intensity or reflectance error ±1% | ±2% | ±5% | ±10% | $r_e$ (I&P) *vs* $r_e$ (P&W) * |
|---|---|---|---|---|---|---|---|---|---|
| MAS 10 (1.62 µm) | +0.09 | –0.10 | +0.10 | 50 | {EQ \o(−,+) }0.7 | {EQ \o(−,+) }1.3 | {EQ \o(−,+) }2.7 | +6 / –4.5 | 0.119 |
| | –0.05 | –0.55 | +0.55 | 5 | {EQ \o(−,+) }0.7 | {EQ \o(−,+) }1.3 | +4 / –3 | +9 / –6 | 0.125 |
| MAS 20 (2.14 µm) | +0.10 | –0.15 | +0.15 | 50 | {EQ \o(−,+) }0.3 | {EQ \o(−,+) }0.6 | {EQ \o(−,+) }1.4 | {EQ \o(−,+) }0.3 | 0.160 |
| | –0.30 | –0.50 | +0.50 | 5 | {EQ \o(−,+) }0.4 | {EQ \o(−,+) }0.7 | {EQ \o(−,+) }2.0 | +4.5 / –3.5 | 0.217 |
| MAS 31 (3.73 µm) | +0.09 | –0.30 | +0.30 | 50 | {EQ \o(−,+) }0.2 | {EQ \o(−,+) }0.3 | {EQ \o(−,+) }0.7 | +1.7 / –1.4 | 0.256 |
| | –0.05 | –0.70 | +0.70 | 5 | {EQ \o(−,+) }0.15 | {EQ \o(−,+) }0.2 | {EQ \o(−,+) }0.6 | {EQ \o(−,+) }1.2 | 0.275 |
| | | | | 1 | {EQ \o(−,+) }0.2 | {EQ \o(−,+) }0.6 | {EQ \o(−,+) }1.4 | {EQ \o(−,+) }2.5 | |
| AVHRR (3.75 µm) | +0.45 | –0.30 | +0.50 | 50 | Same as for MAS 31 | | | | 0.302 |
| | –0.10 | –0.70 | +1.20 | 5<br>1 | | | | | 0.375 |

* I&P denotes Irvine and Pollack (1968) and P&W denotes Palmer and Williams (1974). These computations apply to the case when $\tau_c = 50$ and $r_e = 10$ and 20 µm.

The revised ATBD is largely based on the work of Nakajima and King (1990), in which asymptotic theory is the core of the algorithm. This ATBD has been enriched by Steve Platnick's analysis of error sources in the retrieval of cloud properties. Table 1 summarized errors in retrieving effective radius for each of the MODIS near-infrared channels, as well as the AVHRR 3.75 µm channel. It is shown that errors introduced by the ways of spectral averaging (<R>) and the shift of bandwidth (BW) are relatively minor. The most significant errors arise from uncertainty in the refractive indices of water used and the absolute accuracy of the sensor, due either to instrument calibration or the effects of the atmospheric path. Sources of error in retrievals of optical thickness ($\tau_c$) due to uncertainties in calculation of the visible channel reflectance were also analyzed by Steve Platnick. In general, results show that errors in surface reflectance are probably only of minor concern compared to those from the absolute accuracy of the sensor. Simple analytic approximations to retrieved errors in $\tau_c$ were also developed for these cases.

To confirm that this cloud retrieval code returns correct values, Nakajima and King (1990) performed fundamental tests by synthesizing reflection function data from pre-computed lookup tables at identical gridded points. In addition to the analyses of MCR data, Si-Chee Tsay also modified this code to analyze some MAS data from ASTEX. For the purpose of further testing the statistical package of this retrieval code, Menghua Wang created a pseudo data set directly from the lookup tables. These pseudo data (angular distribution of reflection functions for a homogeneous cloud) were purposely chosen to be away from the gridded mesh consisting of 4 scaled optical thicknesses (0.5, 0.7, 0.9, and 1.1), 7 sun angles (5°, 15°, 25°, 35°, 45°, 55° and 65°), 5 viewing angles (5°, 15°, 25°, 35° and 45°), and 10 azimuth angles (5°, 18°, 38°, 55°, 75°, 95°, 125°, 135°, 148° and 175°) at an effective radius of 5.657 µm. An identical interpolation scheme, used in the retrieval code, was applied to create a total of 1400 pseudo pixels at wavelengths of 0.754, 1.645, and 2.16 µm from the lookup tables. After the test, a couple of minor bugs in this customized statistical code were identified and temporarily fixed by Menghua Wang for delivery to SDST. Permanent fixes of these bugs will be done in the process of standardizing this code.

New lookup tables, particularly for MAS spectral bands at 0.664, 1.621, 2.142, and 3.725 µm, have been generated by Menghua Wang. By comparing results produced from two different Mie scattering and radiative transfer models, it was found that the maximum difference between two sets of lookup tables for reflectance and flux parameters is within 1%. The entire ASTEX data set is in the process of being processed using this retrieval algorithm and selected results are presented below.

A generic formulation of surface bidirectional reflectance distribution function (e.g., Hapke's BRDF model) has been implemented into the DisORT radiative transfer code (version 2, Tsay et al., 1994). Preliminary results show that the surface BRDFs can be simulated reasonably well if the parameters describing the surface properties (e.g., amplitude and width of opposition surge, probability of scattering, and asymmetry factor) are properly chosen. This model will be used to explore our BRDF data measured by the CAR.

*b. MODIS-related Instrumental Research*

The MAS data system is still in the process of being upgraded to record the full complement of 50 spectral channels. However, there was insufficient time to get the analog-to-digital (A/D) converter boards fabricated (by Berkeley Camera Engineering), delivered, assembled into the data system, and cold chamber tested, and still allow time to thoroughly calibrate the MAS prior to the June 1 MAST (Monterey Area Ship Tracks) deployment. Fortunately, there was sufficient time to replace the port 2 and 3 dewars and to adjust the spectral bandpass of the port 4 grating without holding up the schedule. We chose an 11 channel setup during MAST, as has been done in the past, using 10-bit digitization for the 3.725, 8.5, 11 and 12 µm channels and 8-bit digitization for the 0.664, 0.875, 1.623, 1.880, 2.142, 2.28 and 3.90 µm channels. The reflected solar radiation component of the 3.7 µm channel contains important information for the ship track study.

During the MAST deployment, a meeting was called by Michael King at NASA Ames Research Center to get together managers, scientists, engineers, and supporting crew to consolidate the schedule of future MAS activities and related aircraft missions. The MAS is scheduled to be integrated onto C-130, test flown and debugged from July 6 to 15. Then, the C-130 will leave Ames for Prince Albert, Saskatchewan, to participate in the BOREAS mission until August 9. The 50-channel data system integration and testingf of MAS will begin on August 15 and followed by engineering test flights until August 26. Since there will be no ER-2 aircraft available from August 30 to September 19 (before the scheduled SCAR-C deployment), the software checkout of the new data system and radiometric calibration of MAS will be performed during this period of time. The SCAR-C experiment is scheduled to be conducted from September 21 to October 7. The MAS also needs to be shipped, after radiometric calibration of SCAR-C at Ames, to Stennis Space Center, where two weeks will be required to do a thorough spectral calibration of the bandpass characteristics of all 50 spectral channels. Dædalus has shown some deficiency in this capability. It is also advantageous to send the MAS back to GSFC to do a radiometric calibration as well.

Dave Augustine has completed the MAS Quicklook data display software (version 0) which was operated during the MAST deployment. This allows the user to view the raw MAS data in either single channel, three channel simultaneous or RGB composite modes. Other options are an interactive stretch of the color tables (both upper and lower boundaries), tape manipulation (skip files, tape rewind, and position to selected scan) and customize color tables.

In addition to the new 50-channel system, Liam Gumley and Pat Grant recommended that the INS time code come directly from the GPS navigation system.

However, the MAS clock time will also still be recorded. The RS-232 serial navigation data stream will be stored as-is in the MAS scan line blocks (32768 bytes/block, one scan line per two blocks) - none of the navigation data will be unpacked. The new navigation data stream will be entirely ASCII, and thus should be easy to decode. Approximately 500 bytes will be required. The video data will be stored as 2 12-bit words every 3 bytes. This will require some bit-shifting/masking to unpack, but should pose no problems.

Tom Arnold and John Cooper recently worked on MAS calibration, with both the Goddard 48-inch hemisphere and the new Ames 20-inch hemisphere (both with and without the mirror). Some problems with the Ames 20-inch hemisphere were observed, such as the order in which the lamps were turned off (which affects sphere uniformity) and hemisphere loading errors as a function of the distance from the source to the MAS. Initial results of the comparison of the 20-inch hemisphere data using the 45° mirror vs. looking directly into the hemisphere appear consistent with the independent calibration of the mirror.

Nita Walsh and Max Strange completed the installation and adjustment of the CAR (Cloud Absorption Radiometer) before the June MAST deployment. This includes a newly selected UV-B channel in the ozone absorption band at 0.3 µm. This new detector is a UV-enhanced silicon photodiode (UDT-455UV) and the new filter, from Omega Optical, has a 30 nm bandpass with a transmission centered at 300 nm of about 30%. The new, fused silica, focusing lens was fabricated by JML Optical. The 13 channels of the CAR that we have selected for MAST were 0.47, 0.67, 0.30, 0.87, 1.03, 1.27, 1.22, 1.55, 1.64, 1.72, 2.10, 2.20, and 2.30 µm.

Calibration of the CAR using both the six-foot sphere and the 48-inch hemisphere was performed by Tom Arnold and Nita Walsh for all channels, except for the UV-B channel due to the unavailability of a proper source. The CAR was moved out onto the roof of a building for testing while looking at the sky overhead. Representative signals from all channels were recorded on two separate days, while the instrument was aimed directly at the sun and then at cloud cover. This UV channel was set by adjusting it's gain potentiometer until the signal would go into saturation at the same point (i.e., at the same gain switch setting) as the other channels with direct sun illumination. The signal on all channels, from the cloudy sky was also observed. After determining the optimum gain setting for the new detector, proper operation of the UV channel was confirmed in May and during the MAST experiment. This channel will have to be carefully calibrated upon the instrument's return from the field in July. Post-flight calibration will be performed when the calibration sources are returned from the field. An accurate calibration method for the UV channel will be confirmed at that time.

*c. MODIS-related Services*

*1. MODIS-related experiment: MAST*

During the month of June (May 31 - July 1), Michael King, Tom Arnold, Dave Augustine, Liam Gumley, Steve Platnick, Si-Chee Tsay and Menghua Wang devoted ten days to a month of their time to the MAST deployment. Work involving the NASA ER-2 aircraft was performed at Ames Research Center and work involving the UW C-131A aircraft and Operations Center were performed in Monterey.

The main objective of the MAST experiment is to study the physical processes by which ship tracks are formed. More fundamentally, it is to understand how anthropogenic aerosols modify the reflectivity of existing clouds (indirect effect), and thus the earth's radiation balance. The MAST consisted of various NOAA, DMSP and GOES satellites; the NASA ER-2 aircraft carrying the MAS, CALS (Cloud and Aerosol Lidar System) and RAMS (Radiation Measurement System); the University of Washington's C-131A and the United Kingdom's MRF C-130 research aircraft carrying a wide variety of instrumentation to measure atmospheric dynamics, thermodynamics, microphysics, chemistry and radiation; the Naval Research Laboratory Airship (Blimp) and the M/V Research Vessel. In addition, four conventional-powered and one nuclear-powered US Navy Ships participated in the MAST campaign to serve as controlled aerosol sources.

The importance of MAST to MODIS is that ship tracks, which exist on a small scale (minimal meteorological effects), provide a useful laboratory for the study of cloud microphysical changes as well as provide tests of instrumentation and validations of our cloud retrieval algorithm. During the entire experiment, 7 research flights were conducted by the ER-2 aircraft, which flew about 33 flight hours, and 12 research flights were conducted by the C-131A, which flew about 60 hours. Highlights of these flights are as follows:

- Coordinated flights between the ER-2, C-131A and C-130 were conducted over dedicated ships and ships of opportunity, consisting of 5 flights with the C-131A and 4 flights with the C-130.

- One of the ER-2 missions was well coordinated with a NOAA-9 AVHRR satellite overpass. Targets in this mission were extensive stratocumulus clouds with lots of structure and some holes, but no cirrus clouds.

- All of the ER-2 missions performed a mapping grid pattern, consisting of flight legs spaced 30 km apart and parallel in length of 280 km; while two of the missions consisted of repeated flight legs under which the C-131A and C-130 underflew or the NOAA satellite overflew.

- Two of the ER-2 missions measured ship track signatures clearly in all shortwave infrared channels, but the other five missions had stratocumulus clouds that were either thinning during the flight or extensive and solid yet non-susceptible such that ship tracks were not immediately obvious.

- Two of the C-131A missions measured the sky bidirectional transmittance over ocean and stratocumulus clouds but under hazy sky conditions.
- One (and possibly two) of the C-131A missions obtained CAR measurements in the diffusion domain (deep interior of a cloud).
- In addition, the high resolution RC-10 camera obtained a photograph of a cargo ship that produced a distinct track. Also, the MAS visible and shortwave infrared channels observed many glory patterns (direct backscattering) during the entire MAST deployment.

*2. Meetings*

1. Michael King attended (and co-chaired) the Investigators Working Group (IWG) meeting in San Antonio, TX, on 11-13 January, during which he made three presentations: (i) “Project Science Office Update”, (ii) “EOS Validation Plan,” and (iii) “Remote Sensing of Cloud and Surface Properties from Aircraft;”

2. Michael D. King attended the AMS Annual Meeting in Nashville, TN on 23-28 January 1994 and presented an invited paper “The application of EOS to studies of atmospheric radiation and climate;”

3. Si-Chee Tsay attended the 8th Conference on Atmospheric Radiation, AMS Annual Meeting, Nashville, TN on 23-28 January 1994 and presented two papers entitled “A Fourier-Riccati approach to radiative transfer. Part II: Computations of spectral reflectance and heating rates in cirrus-like clouds” (co-author with P. M. Gabriel, M. D. King and G. L. Stephens) and “Remote sensing and retrieval of surface bidirectional reflectance” (co-author with M. D. King);

4. Liam Gumley attended the 8th Conference on Atmospheric Radiation, AMS Annual Meeting, Nashville, TN on 23-28 January 1994 and presented a paper entitled “Multi-sensor remote observations of thin cirrus clouds during FIRE Cirrus II” (co-author with M. D. King and S. C. Tsay);

5. Steven Platnick attend the MODIS cloud mask meeting, held on 28 February-1 March at the University of Wisconsin, Madison, WI, to discuss possible algorithms for cloud masking the MODIS data and to organize the writing of the ATBD;

6. Si-Chee Tsay participated in the Monterey Area Ship Tracks experiment planning meeting in Monterey, CA on 19-21 April 1994 and presented an update of MAS, as well as other instruments, onboard the NASA ER-2 aircraft, as well as described possible flight plans;

7. Michael King, Liam Gumley, Steve Platnick, Si-Chee Tsay, and Menghua Wang attended the MODIS Science Team meeting at Greenbelt, MD on 4-6 May 1994 and presented (i) EOS Project Science Report (King), (ii) Multisensor observations of thin cirrus clouds (Gumley), and (iii) Uncertainties in cloud retrievals (Platnick);

8. Michael King, Steve Platnick, Si-Chee Tsay, and Menghua Wang attended the MODIS Algorithm Theoretical Basis Document (ATBD) review meeting at Landover, MD on 9-11 May 1994 and Michael King presented the ATBD;

9. Michael King co-chaired the EOS ATBD Review Meetings at Landover, MD on 9-11 May (MODIS, CERES, MISR) and 16-17 May (ASTER, MOPITT, LIS, SeaWinds);

10. Si-Chee Tsay participated in the SCAR-C Mission Planning and SCAR-B Update meeting at Greenbelt, MD on 17 May 1994 and presented CAR surface bidirectional reflectance observations and simulations;

11. Si-Chee Tsay attended the AGU Spring meeting in Baltimore, MD on 23-27 May 1994 (co-author a paper on sea ice study) and became a member of the SHEBA Science Working Group;

12. Michael King attended or chaired numerous EOS budget meetings to help formulate the EOS budget from FY95-00.

*3. Seminars*

1. Steven Platnick gave a seminar on “Cloud parameter retrievals and error analysis” to the Radiation and Climate Branch on 16 February.

2. Michael King gave a seminar on “Earth remote sensing from satellite and aircraft” at the Institute of Physics, Minsk, Belarus on 19 April.

## III. Data/Analysis/Interpretation

*a. Data Processing*

Two of the MAS calibration reports, for the 1991 FIRE-II Cirrus and 1992 ASTEX field experiments, were published as NASA Technical Memoranda by Tom Arnold, Michael Fitzgerald, Pat Grant and Michael King. Arnold also completed the first draft of the SCAR-A and TOGA/COARE calibration reports which now are under internal review for publication. The MODIS Airborne Simulator Level-1B Data User’s Guide by Liam Gumley, Paul Hubanks, and Edward Masuoka is now available as NASA Technical Memorandum 104594, MODIS Technical Report Series, vol. 3.

A first attempt was made by Liam Gumley at establishing a MAS WWW (World

Wide Web) site on the 913 branch server. Then, copies of all home page files were transferred to a machine in Code 920 where Paul Hubanks will share responsibility for maintaining the home page. During the month of June, the MAS home page (not including sub-pages, and accesses from redback) was retrieved 445 times, thus it proved the WWW site is very useful as a means of disseminating information about the MAS. This should eventually include a hypertext version of the Level-1B Data User's Guide.

RGB composite images from MAS and the Landsat Thematic Mapper (TM) of flooding near St. Louis were prepared by Liam Gumley for use in the MODIS brochure. This involved "box-averaging" the MAS and TM to 300, 540, and 1020 m pixel sizes to indicate the resolution available from MODIS. In addition, the flooding in the US Midwest during the summer of 1993 was also studied by using MAS data acquired on 29 July 1993 and a Landsat-5 TM cloud-free scene acquired over the St. Louis area on 14 April 1984.

Tom Arnold has worked on the intercomparison between Landsat TM and MAS data for the 3 April 1993 case of CEPEX. So far the results are showing significant differences in the 0.66 and 1.64 µm channels in both the slope and offset of the intercomparison. Some of the scatter in the data are believed to be due to the lack of uniformity in the cloud scene. More careful study is needed to establish a way to calibrate the MAS data obtained during CEPEX.

In the processing of CAR BRDF for flight 1611, Ward Meyer has found and developed a way to eliminate "bad scan" problems which were caused by switching the manual gain during CAR active scans. To properly determine the solar principal plane, the scan range is initially chosen to be greater than a full 360° in azimuth. This permits easy identification of the azimuth angles at 0° and 360° scans in TRANSFORM and also shows any potentially bad scans missed. Many plots were created for SCAR-A flights 1611 and 1612, in haze and above haze, for channels 1 (0.47 µm), 2 (0.67 µm), 4 (0.87 µm), and 9 (1.64 µm). Channel 12 (2.20 µm) data was found to be so noisy that it did not warrant analysis.

Ward Meyer also developed a new type of color survey plot that is analogous to the Quicklook images produced for the MCR and MAS instruments. In this case, however, the spatial resolution perpendicular to the flight line is from zenith to nadir, not just a swath along the surface. The plot is rectangular with the y-axis representing the scan angle and the x-axis containing the scan number range. This permits, in the case of BRDF, an easy opportunity to view succeeding circles to determine whether some features are anomalies or reproducible features. Survey plots can be made for various scan ranges and for any of the channels. The SCAR-A flight 1607 data were used for the initial testing of this technique and found to be very powerful.

*b. Analysis and Interpretation*

The calibrated and geolocated MAS data containing thin cirrus clouds over the

Gulf of Mexico during FIRE-II Cirrus IFO, together with CALS and HIS data, were analyzed by Liam Gumley. An index parameter derived from the MAS nadir reflection functions at 0.68 and 1.62 µm was developed that appeared to serve as a better indicator of thin cirrus clouds than either individual reflection function. Results in a paper entitled "Multi-sensor remote observations of thin cirrus clouds during FIRE Cirrus II" were presented by Liam Gumley at the 8th AMS Conference on Atmospheric Radiation, Nashville TN. Brightness temperature differences from the 8.8, 11, and 12 µm channels were also shown to illustrate the sensitivity of these channels to thin cirrus clouds. To further examine the spatial inhomogeneity effect, a newly developed 2-D radiation model was used by Si-Chee Tsay to simulate the 1.38 µm (similar spectral characteristics to that of 1.93 µm) reflectance. Results in a paper entitled "A Fourier-Riccati approach to radiative transfer. Part II: Computations of spectral reflectance and heating rates in cirrus-like clouds" were presented at the AMS meeting in Nashville.

An extensive examination of our cloud retrieval algorithms is being carried out using the MAS ASTEX data. Another interesting case (other than the previously analyzed flight line 14 on June 17) of cloud microphysics and radiation interaction has been selected to demonstrate the retrieval of the effective radius and optical thickness of these clouds. Figure 1, a direct print out of a MAS quicklook image from our WWW site, shows the reflection function at 0.665 µm. The synoptic condition of this day was: cloud top height about 1000 m and a transition of clean maritime air (left) to highly polluted continental air from Europe (right). To obtain quantitative statistics on these clouds, Fig. 2 shows the marginal probability density function of retrieved cloud optical thickness (Fig. 2a) and effective radius (Fig. 2b). Every 4th pixels and 4th scan line was run through the retrieval code and a simple cloud masking criterion was applied to reject clear or cirrus contaminated pixels. The retrieved optical thickness of cleaner clouds (solid line) is singly peaked around 10 but bimodal with peaks at 13 and 16 for the dirtier clouds (dotted line), which also exhibited a longer tail. Although the retrieved effective radius for both air masses is somewhat complicated, the main difference between these two curves is at the tail of the large droplet sizes. Figures 2c and 2d show the corresponding joint probability density functions of the retrieved optical thickness and effective radius for both air masses. A negative (or positive) correlation is shown on the cleaner (or dirtier) clouds, which is similar to what has been observed during the FIRE-I cases (Nakajima et al., 1991). Analyses of microphysics data (e.g., liquid water content, droplet concentration, effective radius and background CN concentration) of the entire ASTEX dataset are undergoing. These in situ microphysics data, together with retrieved cloud parameters, will be used to establish some statistics about the cloud properties in this region.

Increases in anthropogenic sources of CCN can increase cloud albedo by increasing the concentration and reducing the size of water droplets in low-level water clouds. However, not all clouds are equally susceptible to modification by CCN;

even those in a clean marine environment can show a great variability. During the entire MAST experiment, only two (out of seven) of the ER-2 missions observed ship track signatures clearly in all shortwave infrared channels of the MAS. Figure 3, a direct printout from the quicklook system, shows a distinct ship track measured by MAS. At the visible channel (0.664 µm), the track is not so obvious due to the rich cloud structure. This track is clearly observed in the 3.725 µm channel (also in 1.64 and 2.142 µm). There is no effect of the ship track in the thermal channels (e.g., 11 µm). Clouds on 13 June 1994 were very clean, with low liquid water content and droplet concentration but large effective particle radius. Figure 4 shows one of the tracks observed by MAS on 29 June 1994. The stratocumulus clouds were extensive and solid but had relatively higher liquid water content, droplet concentration and relatively smaller range of effective particle radius. How susceptible these clouds were will be examined in the near future.

In addition to detection of cloud properties, the MAS is also well suited to the monitoring of surface properties from space. The MAS images over the flooded Mississippi and Missouri Rivers near St. Louis on July 29, as well as the Landsat TM (non-flood) data, has been gathered and analyzed by Liam Gumley. In order to quantify the area covered by water, it was necessary to develop a means of separating water from land surface pixels. This was done by applying a threshold to the normalized digital count histograms of both the MAS 0.94 µm and TM 1.65 µm images, as shown in Fig. 5. After careful examinations, the threshold for each image was set at the mean –4 times the standard deviation. Pixel values less than this threshold were identified as water, while pixel values greater than this threshold were identified as land. It was then possible to estimate the fraction of water-covered pixels in each image by dividing the number of water pixels by the total number of pixels in the image. For the MAS image, the fraction of water pixels was about 23.9%, while for the TM image the fraction of water pixels was about 8.5% of the total number of pixels. Thus an estimate of the fraction of flooded pixels in the MAS image can be gained from the difference in the water/land mask fractions, indicating that about 15.4% of the MAS image is covered by ‘unusual’ flood waters. A first draft entitled “Remote Sensing of Flooding in the US Upper Midwest During the Summer of 1993” was completed by Liam Gumley for submittal to the *Bulletin of the American Meteorological Society*.

Ward Meyer and Si-Chee Tsay continue to work on the surface bidirectional reflectance in which data were obtained by CAR for SCAR-A flights 1611 and 1612 (28 July 1993) around the Great Dismal Swamp, VA. This area is characterized by quite uniform vegetation cover. These bidirectional reflectance polar plots were produced for a variety of cases for flights 1611 and 1612 both in haze and above haze. Analysis of these data, together with previous bidirectional reflectance data for sea ice and snow over tundra, were presented by Si-Chee Tsay at the AMS meeting in Nashville on 23-28 January 1994. More theoretical studies, such as fitting of Hapke’s BRDF model, will be conducted in the future.

Besides the surface BRDF, the aerosol properties are also important parameters to be studied. The corresponding transmittance through the haze layer and reflectance above the haze layer were calculated for the 0.47, 0.67, 0.87 and 1.64 µm channels which will be used to deduce the aerosol properties. Figure 6 shows the transmission functions (about 600 m above ground) at 0.47 and 0.87 µm. The dark region at the center of the plot is missing data due to aircraft roll. Since the data were plotted for a full 360° of azimuthal angle, the symmetry of the radiance field may indicate that the haze layer was very homogeneous. However, the different characteristics of transmission at the limb and solar aureole regions between 0.47 and 0.87 µm is due to aerosol spectral properties. Figure 7 shows the reflection functions (about 2000 m above ground) at 0.47 and 0.87 µm. The picture is more complicated because the signal from the surface is contaminated. The hot spot feature (backscattering or the opposition effect) of vegetated surface is still observed at 0.87 µm, but not at 0.47 µm, in a narrow region of the anti-solar direction in the principal plane, even through the haze layer. Another striking feature observed on the 0.87 µm plot is the very dark region around 225° azimuth and 75° nadir direction, near the location of Lake Drummond (the largest natural lake in Virginia). To fully explore these data, comprehensive aerosol physical and optical models, as well as a radiative transfer model, are needed.

## IV. Anticipated Future Actions

a. Continue the work of documentation, standardization, refinement, and integration of our cloud retrieval codes;

b. Continue the effort of reexamining more carefully the retrieval of cloud optical and microphysical properties by using data gathered from MAS and in situ data from Gerber's PVM probe;

c. Complete the development of a quick-look system for the 50-channel MAS in the field and develop methods to conduct calibrations of the MAS near-IR absorption channels;

d. Compare retrieved cloud parameters from the 3.75 µm channel with those obtained from the 0.665 and 2.142 µm channels, and look into the spectral signature of vertical profile in effective particle radius;

e. Complete data analyses of FIRE-II Cirrus observations gathered by the MAS, CLS, and HIS, as well as theoretical studies, and prepare manuscripts for publication;

f. Apply extensively the MODIS cloud retrieval algorithm through all calibrated and geolocated ASTEX data gathered by the MAS, and prepare manuscripts for publication;

g. Start to process and analyze data sets obtained from the MAST field campaign and compare with co-located in situ aircraft data and satellite overpass observations;

h. Continue to analyze the surface bidirectional reflectance measurements obtained during the Kuwait Oil Fire, LEADEX, ASTEX and SCAR-A experiments;

i. Continue to analyze data sets obtained from the TOGA/COARE and CEPEX field campaigns and compare with co-located Landsat data and model simulations.

## V. Problems/Corrective Actions

No problems that we are aware of at this time.

## VI. Publications

1. Arnold, G. T., M. Fitzgerald, P. S. Grant and M. D. King, 1994: *MODIS airborne simulator visible and near-infrared calibration: 1992 ASTEX field experiment*. NASA Technical Memorandum 104599, 19 pp.

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